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APPLICATION NUMBER: *60/537,882*
FILING DATE: *January 22, 2004*

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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No.

INVENTOR(S)		
Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Juan C.	Scalano	Ottawa, Ontario, Canada

Additional inventors are being named on the _____ *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

THERMALLY MODULATED ANTIOXIDANTS

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ENCLOSED APPLICATION PARTS *(check all that apply)*

☑ Specification *Number of Pages* 43
☑ Drawing(s) *Number of Sheets* 3
☐ Application Data Sheet. See 37 CFR 1.76
☐ CD(s), Number _____
☐ Other (specify) _____

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Respectfully submitted,

SIGNATURE _____

TYPED or PRINTED NAME Edwin J. Gale

TELEPHONE (613) 237-5900

Date JAN 22 /04

REGISTRATION NO. 28,584
(if appropriate)
Docket Number: 57128

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FEE TRANSMITTAL for FY 2004

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☐ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT ($) 160.00

Complete if Known	
Application Number	
Filing Date	
First Named Inventor	SCAIANO, Juan C.
Examiner Name	
Art Unit	
Attorney Docket No.	57128

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FEE CALCULATION

1. BASIC FILING FEE

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1001	770	2001	385	Utility filing fee	
1002	340	2002	170	Design filing fee	
1003	530	2003	265	Plant filing fee	
1004	770	2004	385	Reissue filing fee	
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2. EXTRA CLAIM FEES FOR UTILITY AND REISSUE

	Extra Claims		Fee from below	=	Fee Paid
Total Claims	-20** =		x	=	
Independent Claims	- 3** =		x	=	
Multiple Dependent				=	

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
1202	18	2202	9	Claims in excess of 20
1201	86	2201	43	Independent claims in excess of 3
1203	290	2203	145	Multiple dependent claim, if not paid
1204	86	2204	43	** Reissue independent claims over original patent
1205	18	2205	9	** Reissue claims in excess of 20 and over original patent

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FEE CALCULATION (continued)

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1051	130	2051	65	Surcharge - late filing fee or oath	
1052	50	2052	25	Surcharge - late provisional filing fee or cover sheet	
1053	130	1053	130	Non-English specification	
1812	2,520	1812	2,520	For filing a request for ex parte reexamination	
1804	920*	1804	920*	Requesting publication of SIR prior to Examiner action	
1805	1,840*	1805	1,840*	Requesting publication of SIR after Examiner action	
1251	110	2251	55	Extension for reply within first month	
1252	420	2252	210	Extension for reply within second month	
1253	950	2253	475	Extension for reply within third month	
1254	1,480	2254	740	Extension for reply within fourth month	
1255	2,010	2255	1,005	Extension for reply within fifth month	
1401	330	2401	165	Notice of Appeal	
1402	330	2402	165	Filing a brief in support of an appeal	
1403	290	2403	145	Request for oral hearing	
1451	1,510	1451	1,510	Petition to institute a public use proceeding	
1452	110	2452	55	Petition to revive - unavoidable	
1453	1,330	2453	665	Petition to revive - unintentional	
1501	1,330	2501	665	Utility issue fee (or reissue)	
1502	480	2502	240	Design issue fee	
1503	640	2503	320	Plant issue fee	
1460	130	1460	130	Petitions to the Commissioner	
1807	50	1807	50	Processing fee under 37 CFR 1.17(q)	
1806	180	1806	180	Submission of Information Disclosure Stmt	
8021	40	8021	40	Recording each patent assignment per property (times number of properties)	
1809	770	2809	385	Filing a submission after final rejection (37 CFR 1.129(a))	
1810	770	2810	385	For each additional invention to be examined (37 CFR 1.129(b))	
1801	770	2801	385	Request for Continued Examination (RCE)	
1802	900	1802	900	Request for expedited examination of a design application	

Other fee (specify) _____

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SUBMITTED BY				(Complete if applicable)
Name (Print/Type)	Edwin J. Gale	Registration No. (Attorney/Agent)	28,564	Telephone 613-237-6900
Signature				Date JAN 22 04

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THERMALLY MODULATED ANTIOXIDANTS

FIELD OF THE INVENTION

The present invention relates generally to compounds that function as antioxidants. In particular, the present invention pertains to methods for the modulation of antioxidant levels in selected systems.

BACKGROUND TO THE INVENTION

Antioxidants, or more specifically, chain breaking antioxidants are able to stop, delay or slow down the oxidative degradation of materials. In general, the structure of antioxidants is such that it confers on these molecules two key properties: (a) they are generally good hydrogen donors, and (b) the radical produced following hydrogen transfer is unreactive toward oxygen, thus being able to stop the chain reaction responsible for autooxidations. In the case of some antioxidants the radical (b) is capable of scavenging a second chain carrier, thus leading to a 2-1 stoichiometry; such is the case for phenolic antioxidants.

Requirement (b), i.e. lack of reactivity toward oxygen has resulted in many antioxidants containing O-H bonds, since the resulting oxygen centered radicals are frequently unreactive towards molecular oxygen.

In the last few years a few antioxidants have been proposed that do not contain labile O-H bonds, such as Irganox HP-136™ commercialized by Ciba Speciality Chemicals. Related antioxidants can be reviewed, for example, in United States Patents 5,367,008 issued November 22, 1994, and United States Patent 5,428,177, issued June 27, 1995, which are incorporated herein by reference.

Thermo-oxidative degradation can simplistically be described as a two-cycle process. Two different types of reaction work together to create organic radicals by hydrogen abstraction, and to activate molecular oxygen by reaction with the organic radicals, resulting in formation of peroxyl radicals, which in turn act as hydrogen abstraction active species to produce peroxides and organic radicals. Peroxides themselves serve as a source of hydrogen abstraction radicals by homolytic cleavage of the peroxo O-O bond. Different classes of antioxidants exist, which are characterized as primary antioxidants, secondary antioxidants, and carbon-centered radical scavengers. Primary antioxidants mainly act as chain-breaking antioxidants, reacting rapidly with peroxyl radicals. Secondary antioxidants react with peroxo compounds to yield non-radical, non-reactive products. Carbon-centered radical scavengers are very effective in trapping alkyl radicals, and provide powerful processing stability. Typical examples are carbon-centered radicals derived from benzofuranone derivatives.

When using antioxidants whose action is mediated by carbon-centered radicals, suitable precursors are typically employed, which after activation yield the carbon-centered radical. Often, such precursors are designed such that the radical is formed in a process of hydrogen abstraction. This follows a hydrogen transfer process.

There is a continuing need to develop novel antioxidant compounds and methods that enable rapid availability of antioxidant species. In particular, there is a need to develop compounds and methods that allow for modulation of antioxidant levels in a chosen system.

SUMMARY OF THE INVENTION

It is an object of the present invention, at least in preferred embodiments, to provide a compound that can be "activated" to exhibit antioxidant activities.

It is another object of the present invention, at least in preferred embodiments, to provide a method for selective modulation of antioxidant levels in a reaction mixture or other system.

It is another object of the present invention, at least in preferred embodiments, to provide precursors of carbon-centered radicals that are 'self-activating' in response to a change in temperature.

It is another object of the present invention, at least in preferred embodiments, to provide precursors of carbon-centered radicals that are self-activating within a predetermined range of temperature values.

It is another object of the present invention, at least in preferred embodiments, to provide precursors of carbon-centered radicals in which the self-activating process is reversible.

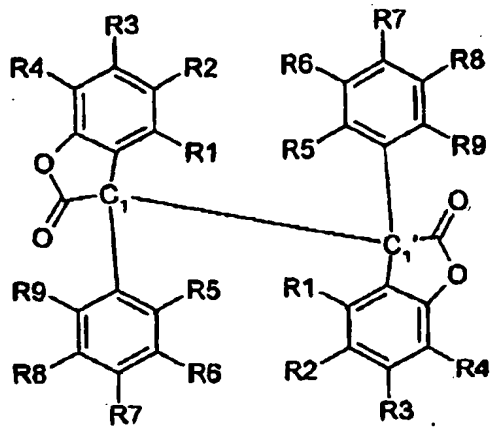
The inventors have established that the mode of operation for specific types of antioxidants, involves the formation of carbon-centered radicals that do not react with oxygen. The inventors have further determined that this mode of operation is most unusual since the vast majority of carbon-centered radicals react with oxygen at rates that approach diffusion control. Following up on this observation, the inventors have discovered a wide range of compounds that have the unusual property of producing carbon centered radicals that either do not react with oxygen, or where the reactivity is greatly attenuated.

The inventors' observations have led to the identification of an entirely new class of antioxidant compounds and systems that can be manipulated according to the ambient temperature conditions. Importantly, these systems present unique opportunities to provide reaction systems in which antioxidant levels are modulated by simple temperature shifts. Such systems may include, but are not limited to, plastics, lubricants, cooling fluids, and pharmaceutical / medical applications.

In accordance with one particular aspect of the instant invention, there is provided a method of providing oxidation protection comprising: providing a composition to be protected against oxidation during a high temperature portion of a thermal cycle; adding an amount of a thermally activatable dormant antioxidant species to the composition; thermally cycling the composition between a low temperature portion of the thermal cycle and the high temperature portion of the thermal cycle, to reversibly dissociate the thermally activatable dormant antioxidant species into a carbon-centered radical active antioxidant species, so as to provide an increased amount of the carbon-centered radical active antioxidant species during the high temperature portion of the thermal cycle relative to the low temperature portion of the thermal cycle.

In accordance with another aspect of the instant invention, there is provided a method for modulating oxidation protection comprising: providing a composition to be protected against oxidation at a first temperature and to other than substantially be protected at a second temperature lower than the first temperature; selecting a thermally activatable dormant antioxidant species for providing an active antioxidant species at the first temperature, the thermally activatable dormant antioxidant species thermally activatable at a temperature between the first and second temperatures; including the thermally activatable dormant antioxidant species in the composition; effecting a change to the temperature of the composition from the second temperature to the first temperature, to induce some of the thermally activatable dormant antioxidant species into the active antioxidant species; and, optionally effecting a change to the temperature of the composition from the first temperature to the second temperature, to induce some of the active antioxidant species back into the thermally activatable dormant antioxidant species.

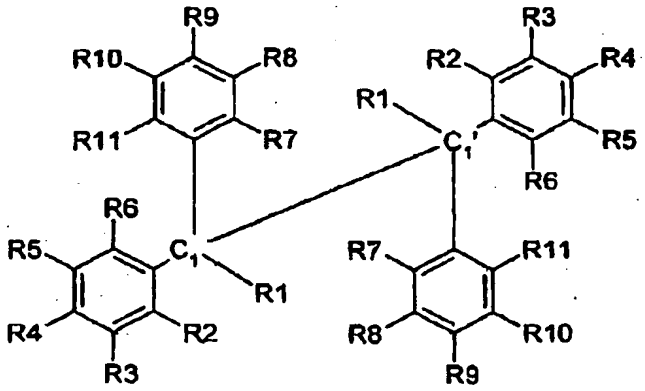
In accordance with yet another embodiment of the instant invention there is provided a chemical product including a compound selected from those of formula 1,



I

wherein R1 to R9 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl;

or of formula II,

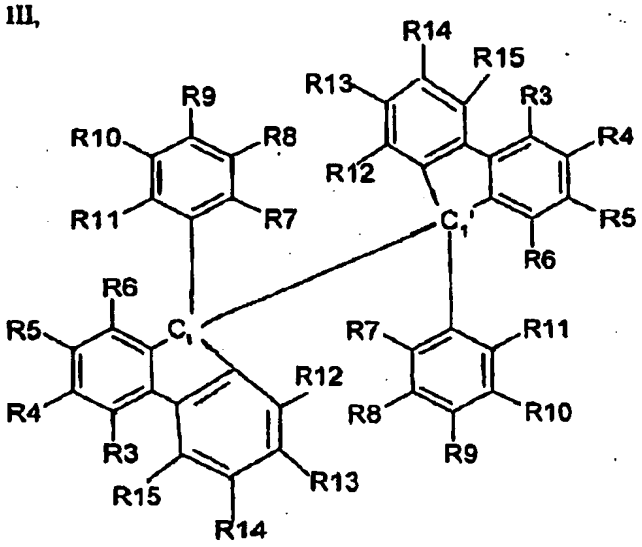


II

wherein R1 represents an electron withdrawing group, most preferably nitrile, and R2 to R11 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-

C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl;

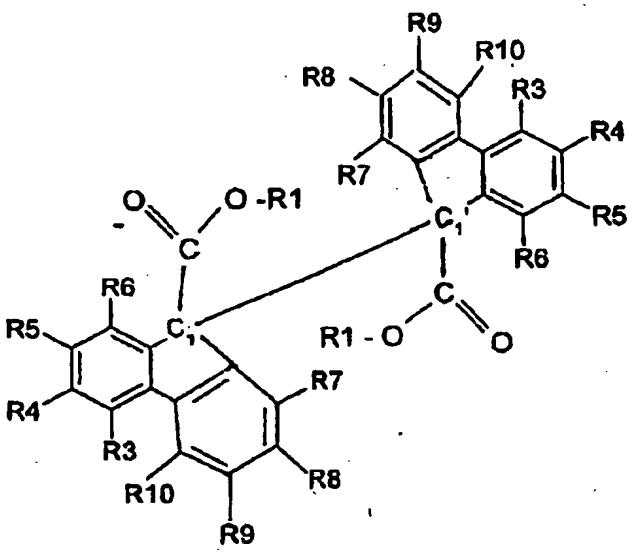
or of formula III,



III

wherein R3 to R15 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl;

or a compound of formula IV,



IV

wherein R1 and R3 to R10 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1-C_{18} alkyl, branched C_1-C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5-C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6-C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl;

the chemical dissociating into two constituent parts through breakage of a C1-C1' labile bond upon heating thereof, each part exhibiting antioxidant activity reflecting their ability to capture free radicals, the two constituent parts preferably reassociating to reform the compound upon cooling thereof.

In accordance with still another aspect of the instant invention, there is provided an improvement in a periodically thermally cycling system, the system including a composition that is subject to substantially more oxidative degradation during a high temperature portion of the thermal cycle than during a low temperature portion of the thermal cycle, the improvement comprising: a chemical component forming a part of the composition, for reversibly dissociating in response to temperature changes of the

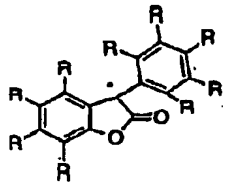
composition upon repeated thermal cycling between the low temperature portion of the thermal cycle and the high temperature portion of the thermal cycle, so as to provide an amount of an active antioxidant species during the high temperature portion of the thermal cycle that is substantially larger than an amount of the active antioxidant species during the low temperature portion of the thermal cycle.

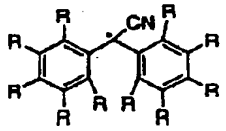
In accordance with another aspect of the present invention there is provided an antioxidant precursor compound of the formula:

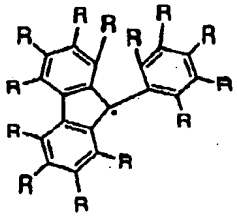
A - B

wherein A and B are the same or different, each of A and B comprise a monocyclic or multicyclic aromatic and / or heterocyclic ring system, optionally substituted at one or more positions;

and wherein A and B are connected via a labile bond, and are susceptible to disassociation through breakage of the labile bond upon exposure of said compound to a predetermined temperature shift from a lower temperature to a higher temperature, thereby to generate corresponding free radicals A and B suitable for use as antioxidants. Preferably A and B are identical. Most preferably, each of A and B are independently selected from the group consisting of the following structures, which may be substituted or unsubstituted:







wherein each aromatic or heterocyclic ring may be unsubstituted or substituted with one or more identical or different substituents.

Preferably the compound has a formula selected from a compound of formula I, II, III, and IV as described herein.

Preferably, the compounds A-B exclude the compound of formula (11) disclosed in United States Patent 5,367,008 or the compound of formula (10) disclosed in United States Patent 5,428,177 or the dimeric form of Irganox HP-136 (Ciba Speciality Products) or related dimeric products.

In another aspect of the present invention there is provided the use of the compound A-B as described herein as a selectively activatable antioxidant.

In another aspect of the present invention there is provided an antioxidant composition selectively transferable between:

(a) a low temperature non-active state wherein the composition comprises a dimeric compound A-B substantially devoid of antioxidant properties; and

(b) a high temperature active state wherein the composition comprises monomeric free radicals A and B, at least one of which exhibits antioxidant properties.

More preferably the compound A-B is the compound of Formula I, II, III, IV, IA, IB, IIA, or IIIA, as described herein.

In another aspect of the present invention there is provided a method for selectively modulating a concentration of antioxidant molecules in a reaction mixture or target environment, the method comprising the steps of:

(a) providing a composition comprising the compound A-B as described herein;

(b) adding the composition to the reaction mixture or target environment;

(c) adjusting the temperature of the reaction mixture or target environment so as to modulate the concentration of antioxidant molecules in accordance with the degree of association or disassociation of A and B.

In a preferred aspect of the present invention there is provided a compound of formula IA, IB, IIA or IIIA as described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows the absorption spectra of the monomer-radical obtained by thermal dissociation of compound IB at different temperatures;

Figure 2 provides a flow diagram of a method of providing oxidation protection according to an embodiment of the instant invention; and,

Figure 3 provides a flow diagram of a method of providing oxidation protection according to another embodiment of the instant invention.

Figure 4 provides a flow diagram of a method for selectively modulating a concentration of antioxidant molecules in a reaction mixture or target environment in accordance with one embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following description is presented to enable a person skilled in the art to make and use the invention, and is provided in the context of a particular application and its requirements. Various modifications to the disclosed embodiments will be readily apparent to those skilled in the art, and the general principles defined herein may be

applied to other embodiments and applications without departing from the spirit and the scope of the invention. Thus, the present invention is not intended to be limited to the embodiments disclosed, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

Definition of "dimer" and "monomer" - It is to be understood that throughout the description and in the claims that follow, the term "dimer" refers to compounds comprising two major moieties connected via a covalent labile bond. Each dimer may dissociate via breakage of the labile bond to form two monomeric free radicals, each comprising one of the major moieties of the dimer. At least in preferred embodiments, the term may also refer to a "head-to-head dimer". It will further be understood that the term 'dimer' preferably, but not necessarily, refers to compounds wherein the two major moieties are identical. Four specific and non-limiting examples of preferred "head-to-head dimers" comprising identical major moieties are the "head-to-head dimers" of formula I, formula II, formula III and formula IV described herein.

Definition of " thermally modulated antioxidant " - The expression "thermally modulated antioxidant" is intended to encompass both dimeric (associated) and monomeric (dissociated) states of the antioxidant compounds of the present invention. For example, in selected embodiments such thermally modulated antioxidant compounds may take the form of "thermally activatable dormant antioxidant" species at lower temperatures, and yet at higher temperatures undergo dissociation to form "carbon-centered radical antioxidant" species. In this way, the thermally modulated antioxidants of the present invention can undergo a transition (preferably a reversible transition) between active radical and inactive non-radical states.

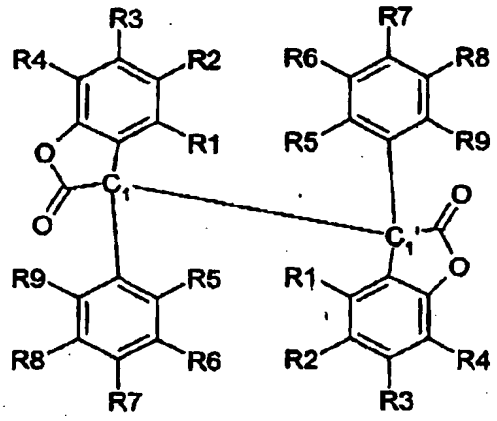
In principle, stable or persistent free radicals can act as antioxidants, i.e., a stable free radical that is either capable of trapping carbon centered or peroxyl radicals can act as an antioxidant, since such trapping will lead to a disruption of the oxidation chain. In fact, stable radicals or their precursors (HALS) are well established polymer additives.

The present invention pertains, at least in preferred embodiments, to compounds that are not themselves good antioxidants, since they are neither free radicals, nor do they have any labile hydrogen atoms. Because of their very low bond dissociation energy (normal C-C bond energies are much higher, typically 80-90 kcal/mol) these compounds dissociate at moderately high temperatures producing a large concentration of free radicals that are themselves capable of scavenging the radicals that mediate the oxidative degradation of materials. These compounds can be regarded as "dormant" antioxidants. Their antioxidant activities are activated by heating. Some examples of the compounds of the present invention produce a low radical concentration, for example at 40 °C, but the radical concentration is greatly enhanced at for example 100°C or higher. It is possible to achieve large concentrations of antioxidant radicals, with 10 percent or more of the dimeric compound being dissociated into active antioxidant (monomeric) form.

An important preferred characteristic of the compounds of the present invention is the reversibility of the dimer to monomer transition. Thus, if the samples containing the compounds are cooled after a period of heating, the dimeric compound may reform and again exhibit dormancy in terms of antioxidant properties. Most preferably, the compounds of the present invention can be subjected to multiple cycles between inactive (dimeric) and active antioxidant (monomeric) forms.

The present invention pertains to a wide range of compounds each comprising a labile C-C bond. The nature of the moieties adjacent the labile bond effectively determines the bond dissociation energy (DBE) of the labile bond. Therefore, the present invention pertains to a range of compounds with a range of BDE values, such that each compound dissociates into corresponding monomer radicals at a different predetermined temperature. In this way, a compound of the invention can be selected and tailored to a specific process or use in accordance with its expected dissociation temperature or temperature range.

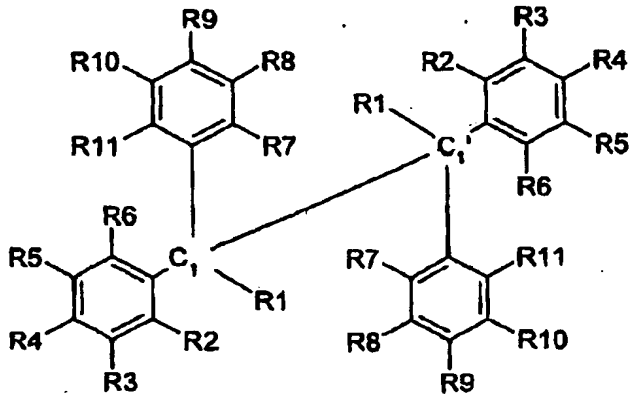
According to selected embodiments of the present invention, 'head-to-head' dimeric compounds are utilized as thermally activatable dormant antioxidants. Presented below are some non-limiting examples of preferred head-to-head dimeric compounds that are encompassed within the scope of the instant invention. A first non-limiting example are the compounds of formula I,



I

Preferred compounds of formula I are those wherein R1 to R9 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl, and C_6 -C_{20} aryl. Further preferred compounds of formula I are those wherein the C_5 -C_8 cycloalkyl groups carry C_1 -C_{18} alkyl groups as substituents. Further preferred compounds of formula I are those wherein the C_6 -C_{20} aryl groups carry C_1 -C_{18} alkyl groups as substituents.

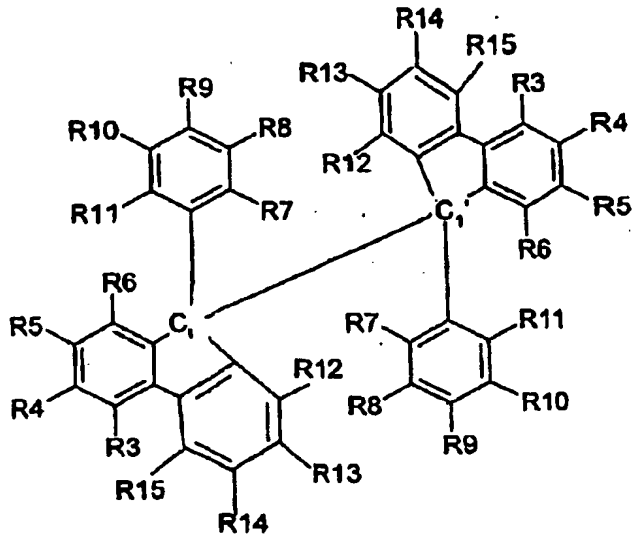
A second non-limiting example are the compounds of formula II,



II

Preferred compounds of formula II are those wherein R1 represents an electron withdrawing group, most preferably nitrile, and R2 to R11 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl, and C_6 -C_{20} aryl. Further preferred compounds of formula II are those wherein the C_5 -C_8 cycloalkyl groups carry C_1 -C_{18} alkyl groups as substituents. Further preferred compounds of formula II are those wherein the C_6 -C_{20} aryl groups carry C_1 -C_{18} alkyl groups as substituents.

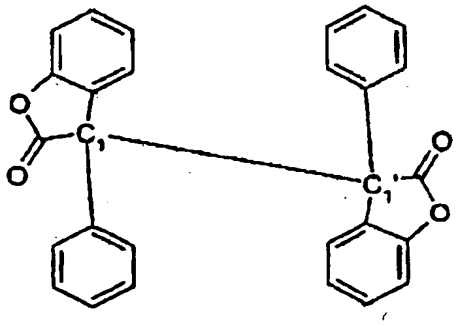
A third non-limiting example are the compounds of formula III:



III

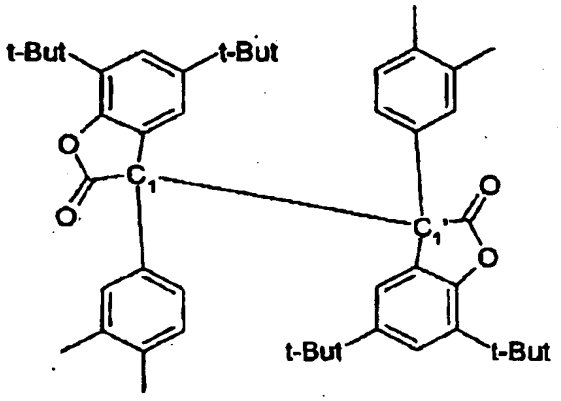
Preferred compounds of formula III are those wherein R3 to R15 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-$_{18}$ alkyl.

A preferred compound of formula I, in which R1, R2, R3, R4, R5, R6, R7, R8, and R9 are hydrogen, is illustrated at formula IA, below:



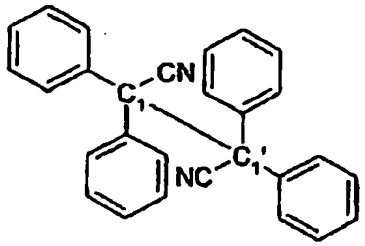
IA

Another preferred compound of formula I, in which R1, R3, R5, R6, and R9 are hydrogen, R2 and R4 are tert-butyl, R7, and R8 are methyl, is illustrated at formula IB, below:



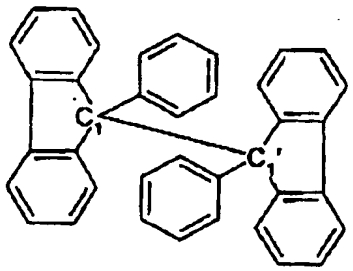
IB

A preferred compound of formula II, in which R1 is a nitrile group, and R2, R3, R4, R5, R6, R7, R8, R9, R10, and R11 are hydrogen, is illustrated at formula IIA, below:



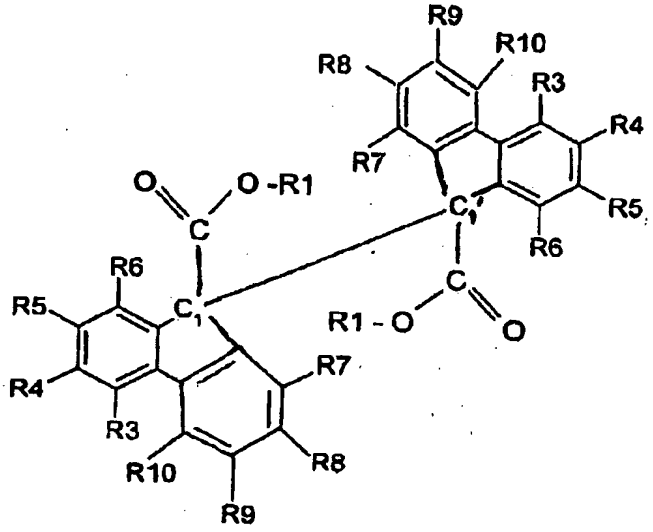
IIA

A preferred compound of formula III, in which R3, R4, R5, R6, R7, R8, R9, R10, R11, R12, R13, R14 and R15 are hydrogen, is illustrated at formula IIIA, below:



IIIA

A fourth non-limiting example are the compounds of formula IV,

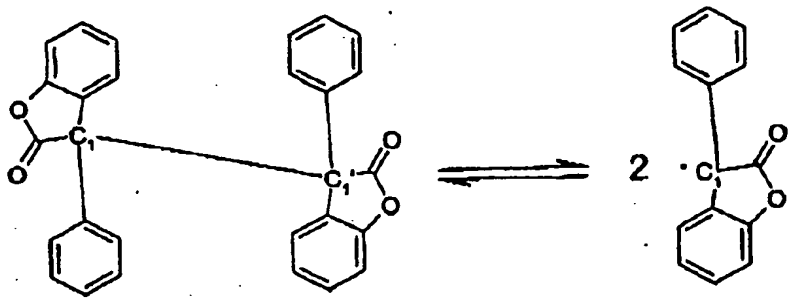


IV

Preferred compounds of formula IV are those wherein R1 and R3 to R10 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1-C_{18} alkyl, branched C_1-C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_3-C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6-C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl.

One of ordinary skill in the art will envisage other similar head-to-head dimers that may be used with the methods according to embodiments of the invention.

The compounds of formula I, formula II, formula III, and formula IV are characterized by a weak C_1-C_1' bond. Upon heating, at least a portion of the compound of formula I, formula II, formula III, or formula IV may undergo a C-C bond cleavage reaction, to produce a pair of radical-monomers, each one of the radical-monomers being a carbon-centered radical. It is the carbon-centered radicals, and not the compound itself, that principally function as an active antioxidant species. It should be noted that the antioxidant activity does not require or involve hydrogen transfer. Preferably, the radical-monomers resulting from the dissociation of the dimeric compounds are stable carbon-centered radicals with greatly attenuated reactivity toward oxygen. Without wishing to be bound by theory, it is believed that the lack of reactivity toward oxygen is attributable, at least in part, to several parameters, including but not limited to (a) benzylic resonance stabilization; (b) favorable stereoelectronic effects; (c) unpaired spin delocalization on heteroatoms and particularly oxygen; (d) electron withdrawing effects, and (e) steric effects.



IA IAm (1)

Equation 1 illustrates a C-C bond cleavage reaction for a specific and non-limiting example of compound IA, which dissociates reversibly to form two carbon-centered radical-monomers IAm. Thus, heating effectively "activates" the antioxidant properties of the dimeric compounds by formation of the corresponding radical monomers. For example, when in solution, heating a sample compound to a temperature of 40°C may produce a small concentration of the radical-monomer (IAm, for instance), whereas heating to 100°C produces a significantly larger concentration of the radical monomer.

Equation 1 also illustrates the temperature dependent chemical equilibrium between the dimeric compound and its corresponding radical monomer. The temperature dependent equilibrium is responsible for the fact that a radical-dimer of formula I, formula II, formula III, or formula IV is regenerated upon cooling. Advantageously, the temperature dependent equilibrium allows one to design antioxidants with tailor-made properties, such as for example having a desired minimum activity at a specific temperature. The temperature dependent equilibrium may also enhance the lifetime and shelf life properties of an antioxidant according to the instant invention.

Temperature dependent absorption studies have been carried out in order to determine the bond dissociation energy (BDE) for the preferred dimers of formula IA, IB, IIA and IIIA. In particular, the monomer-radical resulting from the dissociation of each dimeric compound has characteristic absorptions in the ultraviolet and visible regions. These

absorptions are used to monitor the presence of the monomer-radicals in chemical equilibrium, such as for example the one illustrated at equation 1 for compound IA.

At a predetermined lower temperature the absorptions observed are different in comparison with the absorptions observed at the higher temperature ranges. However, when a sample of a compound of the invention is heated and subsequently cooled, the absorbance spectrum is similar if not identical before heating and after heating. These observations, together with other data, indicate that the dimer dissociation/formation is a reversible process.

Referring now to Figure 1, shown are the temperature dependent absorbance spectra of the monomer-radical obtained by thermal dissociation of compound IB in toluene. In particular, spectra were obtained for temperatures between 48 °C and 111 °C. From the corresponding monomer absorbance spectra, values for the BDE of the C_1-C_1' bond of compound IB are obtained. Data obtained from the temperature dependent study are analyzed using a simplified form of the van't Hoff equation together with Beer's law. Accordingly, the experimental absorbance A is expressed as shown in equation 2:

$$\ln A = \frac{\ln (\varepsilon^2 \ell^2 [D])}{2} + \frac{\Delta S}{2R} - \frac{\Delta H}{2RT} \qquad (2)$$

where ΔH, which corresponds to BDE, is obtained from the slope of an Arrhenius plot of lnA vs. $1/T$. Similar temperature dependent studies were carried out to determine the BDE of compounds IA, IIA and IIIA. The experimentally obtained BDE values are tabulated in Table 1.

Dimer formula	C_1-C_1' BDE (kcal/mol)
IA	22.2
IB	22.8
IIA	26.2
IIIA	15.2

Table 1: Experimentally obtained BDE values.

The data presented in Table 1 indicate that the BDE values of the compounds IA, IB, IIA, and IIIA are in a range between 15 and 26 kcal/mol, about four to five times lower than a

value between 80 and 90 kcal for a typical C-C bond. The data presented in Table 1 also indicate that the compounds according to the instant invention have different operating temperatures. For example, at 100°C the compound according to formula IIIA is about 670,000 times more effective than the compound according to formula IIA in producing free radicals in the active form.

The apparent stability of the compounds in Table 1 is believed to be due to the intrinsic lack of reactivity toward oxygen, which makes the back reaction to reform the dimeric compound the preferred reaction for the radical-monomer. Thus, the compounds of the present invention present the opportunity, at least in preferred embodiments, for repeated cycling between antioxidant (active) and dormant forms without significant degradation. Given the current knowledge of radical stabilities, a person of skill in the art will understand how to design materials in accordance with the instant invention that extend the BDE range above 26 kcal/mol, or below 15 kcal/mol.

Referring now to Figure 2, shown is a simplified flow diagram of a method of providing oxidation protection according to an embodiment of the instant invention, wherein the oxidation protection occurs during the high temperature portion of a high temperature / low temperature thermal cycle. At step 100, a composition to be protected against oxidation during the high temperature portion of a thermal cycle is provided. At step 102 an amount of a thermally activatable dormant antioxidant species is added to the composition. At step 104, the composition is thermally cycled between the low temperature portion of the thermal cycle and the high temperature portion of the thermal cycle, causing dissociation of the thermally activatable dormant antioxidant species into the carbon-centered radical active antioxidant species, so as to provide an increased amount of the carbon-centered radical active antioxidant species during the high temperature portion of the thermal cycle relative to the low temperature portion of the thermal cycle. Preferably, the thermally activatable dormant antioxidant species that is added at step 102 is one of the compounds of formula I, formula II, formula III, and formula IV.

Preferably, the antioxidant species that are utilized with the method according to Figure 2 remain substantially in a dormant form until thermally activated, such as for instance by thermally cycling the composition between the low temperature portion of the thermal cycle and the high temperature portion of the thermal cycle. When the composition is maintained within the high temperature portion of the thermal cycle, the active antioxidant species scavenges the radicals that mediate the oxidative degradation of materials. When the composition, and therefore the active antioxidant species, are cooled, the active antioxidant species become dormant once again, and can be reused during subsequent thermal cycles. The method according to figure 2 is suited for use with compositions that may be subject to heat-cold cycles. For instance, some exemplary and non-limiting types of compositions include some plastics, lubricants, cooling fluids, and medical / pharmaceutical applications. Preferably, the method utilizes thermally activatable dormant antioxidant species that have excellent fast response to repetitive hot-cold cycles, making the method suitable for use with systems that are subject to sudden, or "flash", changes in temperature.

Referring now to Figure 3, shown is a simplified flow diagram of a method of providing oxidation protection according to another embodiment of the instant invention. At step 110, a composition is provided that is to be protected against oxidation at a first temperature and that is to other than substantially be protected at a second temperature lower than the first temperature. At step 112, a thermally activatable dormant antioxidant species is selected for providing an active antioxidant species at the first temperature, the thermally activatable dormant antioxidant species thermally activatable at a temperature between the first and second temperatures. At step 114, the thermally activatable dormant antioxidant species is included in the composition. At step 116, a change is effected to the temperature of the composition from the second temperature to the first temperature, to induce some of the thermally activatable dormant antioxidant species into the active antioxidant species. At step 118, a change is effected to the temperature of the composition from the first temperature to the second temperature, to induce some of the active antioxidant species back into the thermally activatable dormant antioxidant species. Preferably, the thermally activatable dormant antioxidant species that is

included at step 114 is one of the compounds of formula I, formula II, formula III, and formula IV.

Step 112 recites selecting a thermally activatable dormant antioxidant species for providing an active antioxidant species at the first temperature. For instance, a particular thermally activatable dormant antioxidant species having a known activation temperature or a known activation temperature range coinciding approximately with the first temperature is selected from a plurality of available thermally activatable dormant antioxidant species. Preferably, the thermally activatable dormant antioxidant species is selected from a list of available thermally activatable dormant antioxidant species, the list including data relating to activation temperature, solvent compatibility, recommended uses, etc. for a plurality of thermally activatable dormant antioxidant species. Optionally, the step of selecting includes a step of preparing a thermally activatable dormant antioxidant.

Preferably, the antioxidant species that are utilized with the method according to Figure 3 remain substantially in a dormant form until thermally activated, such as for instance by thermally cycling the composition between the low temperature portion of the thermal cycle and the high temperature portion of the thermal cycle. When the composition is maintained within the high temperature portion of the thermal cycle, the active antioxidant species scavenges the radicals that mediate the oxidative degradation of materials. When the composition, and therefore the active antioxidant species, are cooled, the active antioxidant species become substantially dormant once again, and can at least in preferred embodiments be reused during subsequent thermal cycles. The method according to figure 3 is well suited for use with compositions that may be subject to heat-cold cycles. For instance, some exemplary and non-limiting types of compositions include some plastics, lubricants, cooling fluids, and medical / pharmaceutical applications. Preferably, the method utilizes thermally activatable dormant antioxidant species that have excellent fast response to repetitive hot-cold cycles, making the method suitable for use with systems that are subject to sudden, or "flash", changes in temperature.

Another preferred method of the invention is illustrated with reference to Figure 4. In Figure 4 there is at step 130 provided a compound of formula A-B, wherein the compound A-B is substantially devoid of antioxidant properties, and is capable of dissociation into components A and B upon heating thereof, wherein at least one of A and B pertains to a radical exhibiting antioxidant activities. At step 132 the composition is added to a selected reaction mixture or other target environment. Moreover, at step 134 the temperature of the reaction mixture or target environment is adjusted so as to modulate the concentration of antioxidant molecules in accordance with the degree of association or disassociation of A and B. The step of adjusting may pertain to a simple temperature shift, or in alternative embodiments may pertain to several temperature steps or continual temperature changes over a period of time, thereby to modulate and vary the concentration of active antioxidant species in the system.

Two representative preparations will now be outlined in detail below, by way of specific and non-limiting examples.

PREPARATIVE EXAMPLE 1 – Preparation of the compound according to formula IA

The dimer of formula IA was prepared by photolysis of di-tert-butyl peroxide in the presence of the corresponding monomer. A 500 mL Pyrex flask equipped with a magnetic stirring bar was used as the synthesis reactor. In the flask were placed 3-phenyl-isocoumaranone (10 g, 47.5 mmol), *tert*-butyl peroxide (100 mL, 544.3 mmol) and benzene (150 mL). The stirred solution was bubbled with nitrogen for 20 minutes and irradiated at 350 nm for 62 hours at 30°C. The irradiation dose in the UVA region of the spectrum (320 to 400 nm) was approximately 1.2 mJ/cm^2. The resulting suspension was concentrated using a rotatory evaporator. The solid residue was washed with cold diethyl ether until a white solid was obtained. The white solid was then recrystallized from diethyl ether to furnish 6.2g of compound IA as a white solid (63% yield).

PREPARATIVE EXAMPLE 2 - Preparation of the compound according to formula IIIA

The dimer according to formula IIIA was obtained in a one-pot synthesis in 51% yield from the addition of 9-phenyl-9-fluorenol to stoichiometric TMS chloride and excess NaI in acetone followed by subsequent work-up of released molecular iodine with 10% sodium thiosulphate. The practically insoluble dimer was recovered from the filtration of a two-phase system of dichloromethane and aqueous $Na_2S_2O_3$. The dimer is soluble in dichloromethane, and following phase separation can be recovered by evaporation of the solvent.

The thermally activated dormant antioxidants according to the instant invention are possibly used to protect materials that are subjected to heat-cold cycles, including plastics, lubricants, cooling fluids, and medical or pharmaceutical applications. In preferred embodiments of the present invention, the compounds disclosed are suitable for use in situations in which sudden flash changes in temperature occur. Potential fields of applications include oils in closed systems that are subjected to heating, oils in agricultural machines that circulate into a high temperature environment for a brief period, thermo-set resins, thermoplastic resins, and protective films subjected to heat, among others.

Optionally the thermally activated dormant antioxidants may be used in conjunction with a "common" antioxidant, such as for example an anti-oxidant that provides protection at room temperature, so as to provide anti-oxidant protection over a wide range of temperatures.

Numerous other embodiments may be envisaged without departing from the spirit and scope of the invention.

Claims

1. A method of providing oxidation protection, comprising:

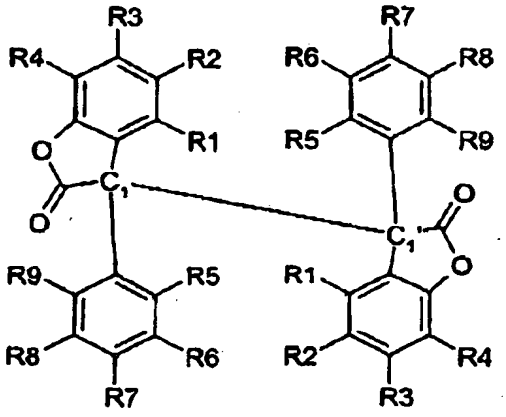
providing a composition to be protected against oxidation during a high temperature portion of a thermal cycle;

adding an amount of a thermally activatable dormant antioxidant species to the composition;

thermally cycling the composition between a low temperature portion of the thermal cycle and the high temperature portion of the thermal cycle, to reversibly dissociate the thermally activatable dormant antioxidant species into a carbon-centered radical active antioxidant species, so as to provide an increased amount of the carbon-centered radical active antioxidant species during the high temperature portion of the thermal cycle relative to the low temperature portion of the thermal cycle.

2. A method according to claim 1, wherein the thermally activatable dormant antioxidant species is a dimeric compound that reversibly dissociates to form two corresponding carbon-centered radical monomers, each of the two carbon-centered radical monomers being active antioxidant species.

3. A method according to claim 1, utilizing a compound of formula I as the thermally activatable dormant antioxidant species:



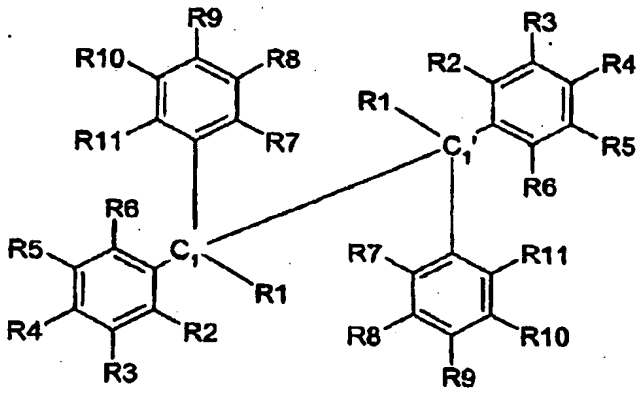
I

wherein R1 to R9 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl.

4. A method according to claim 3, wherein the C_5 -C_8 cycloalkyl groups carry C_1 -C_{18} alkyl groups as substituents.

5. A method according to claim 3, wherein the C_6 -C_{20} aryl groups carry C_1 -C_{18} alkyl groups as substituents.

6. A method according to claim 1, utilizing a compound of formula II as the thermally activatable dormant antioxidant species :



II

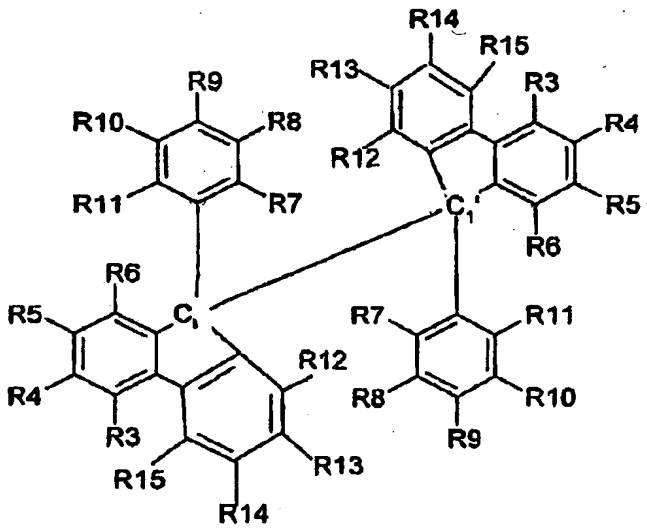
wherein R1 represents an electron withdrawing group, most preferably nitrile, and R2 to R11 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5

-C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl. optionally substituted with one or more C_1-C_{18} alkyl

7. A method according to claim 6, wherein the C_5 -C_8 cycloalkyl groups carry C_1 -C_{18} alkyl groups as substituents.

8. A method according to claim 6, wherein the C_6 -C_{20} aryl groups carry C_1 -C_{18} alkyl groups as substituents.

9. A method according to claim 1, utilizing a compound of formula III as the thermally activatable dormant antioxidant species:



III

wherein R3 to R15 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-

C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl.

10. A method of modulating oxidation protection, comprising:

providing a composition to be protected against oxidation at a first temperature and to other than substantially be protected at a second temperature lower than the first temperature;

selecting a thermally activatable dormant antioxidant species for providing an active antioxidant species at the first temperature, the thermally activatable dormant antioxidant species thermally activatable at a temperature between the first and second temperatures;

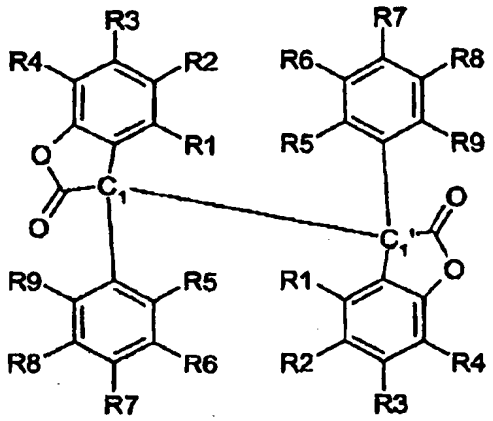
including the thermally activatable dormant antioxidant species in the composition;

effecting a change to the temperature of the composition from the second temperature to the first temperature, to induce at least some of the thermally activatable dormant antioxidant species into the active antioxidant species; and,

optionally effecting a change to the temperature of the composition from the first temperature to the second temperature, to induce some of the active antioxidant species back into the thermally activatable dormant antioxidant species.

11. A method according to claim 10, wherein the thermally activatable dormant antioxidant species is a dimeric compound that reversibly dissociates through breakage of a labile C-C bond to form two carbon-centered radicals, at least one of the two carbon-centered radicals being active antioxidant species.

12. A method according to claim 10, utilizing a compound of formula I as the the thermally activatable dormant antioxidant species:



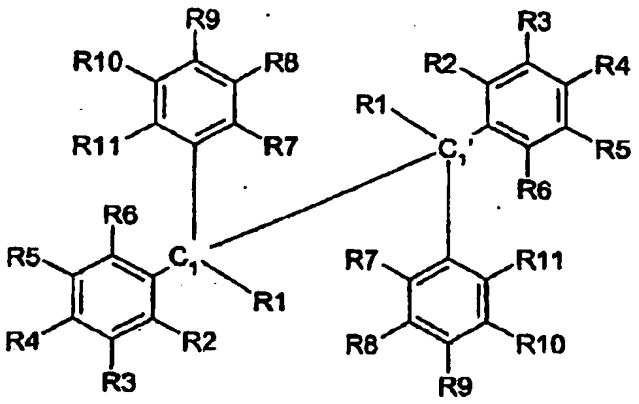
I

wherein R1 to R9 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl.

13. A method according to claim 12, wherein the C_5 -C_8 cycloalkyl groups carry C_1 -C_{18} alkyl groups as substituents.

14. A method according to claim 12, wherein the C_6 -C_{20} aryl groups carry C_1 -C_{18} alkyl groups as substituents.

15. A method according to claim 10, utilizing a compound of formula II as the thermally activatable dormant antioxidant species:



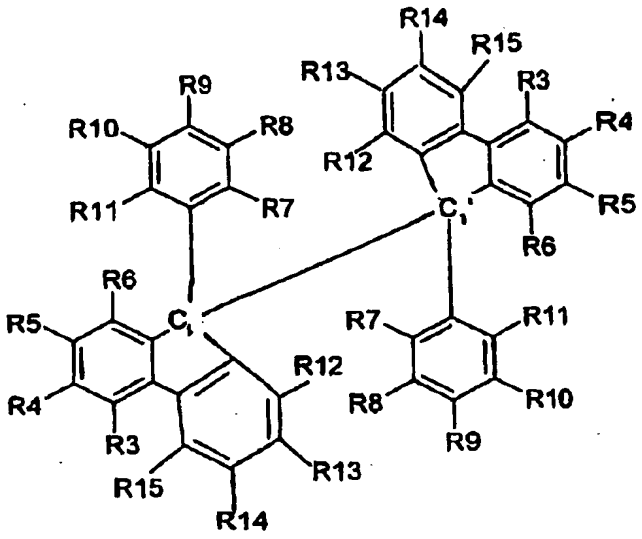
II

wherein R1 represents an electron withdrawing group, most preferably nitrile, and R2 to R11 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl.

16. A method according to claim 15, wherein the C_5 -C_8 cycloalkyl groups carry C_1 -C_{18} alkyl groups as substituents.

17. A method according to claim 15, wherein the C_6 -C_{20} aryl groups carry C_1 -C_{18} alkyl groups as substituents.

18. A method according to claim 10, utilizing a compound of formula III as the thermally activatable dormant antioxidant species:



III

wherein R3 to R15 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl.

19. A method according to claim 11, wherein the thermally activatable dormant antioxidant species reversibly dissociates via a C-C bond cleavage reaction to form the two carbon-centered radicals.

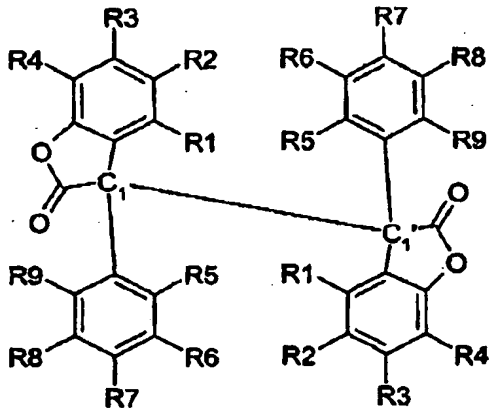
20. A method according to claim 19, wherein the C-C bond cleavage reaction relates to cleavage of a C-C bond having a bond dissociation energy of less than 50 kcal/mol.

21. A method according to claim 19, wherein the C-C bond cleavage reaction relates to cleavage of a C-C bond having a bond dissociation energy of less than 25 kcal/mol.

22. A method according to claim 10, wherein the step of including the thermally activatable dormant antioxidant species in the composition comprises adding an amount of the thermally activatable dormant antioxidant species to the composition.

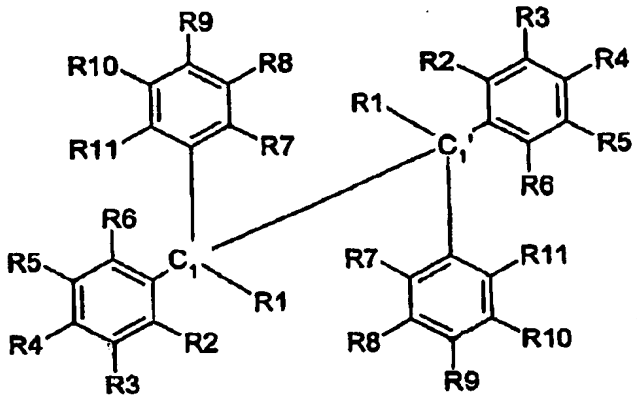
23. A method according to claim 11, wherein the step of including the thermally activatable dormant antioxidant species in the composition comprises adding an amount of the thermally activatable dormant antioxidant species to the composition.

24. A composition comprising a compound of formula I,



I

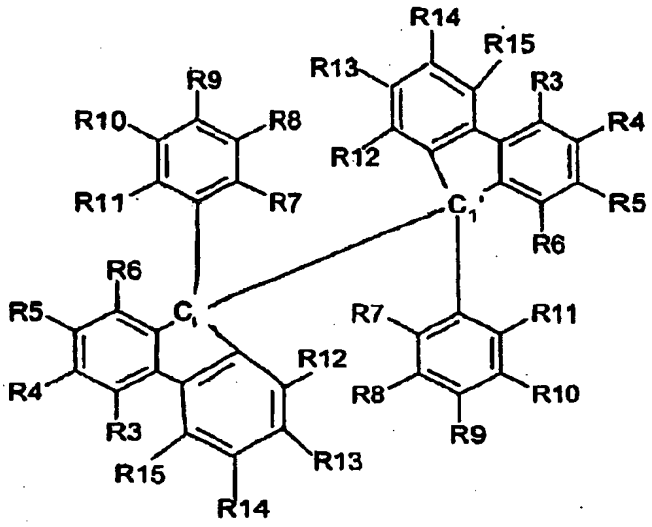
wherein R1 to R9 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl;
or of formula II,



II

wherein R1 represents an electron withdrawing group, most preferably nitrile, and R2 to R11 are the same or different, each representing a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl;

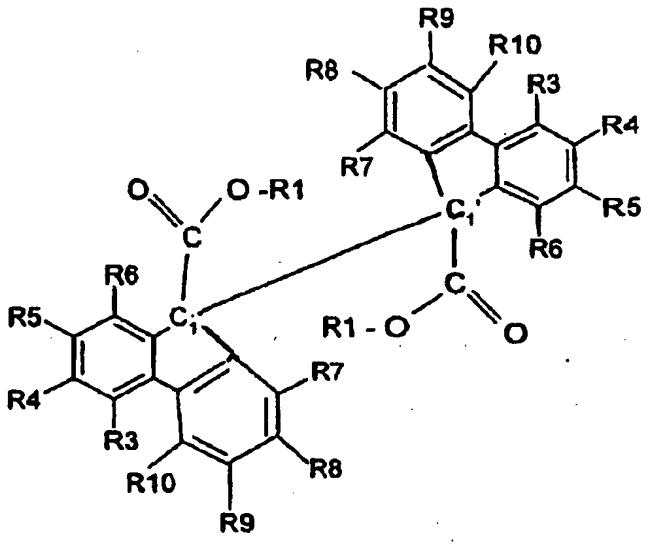
or of formula III,



III

wherein R3 to R15 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl,

or of formula IV:



IV

wherein R1 and R3 to R10 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1-C_{18} alkyl, branched C_1-C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5-C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6-C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl;

the chemical dissociating into two constituent parts through breakage of a C_1-C_1' labile bond through heating thereof, each part exhibiting antioxidant activity, the two constituent parts preferably reassociating to reform the compound upon cooling thereof.

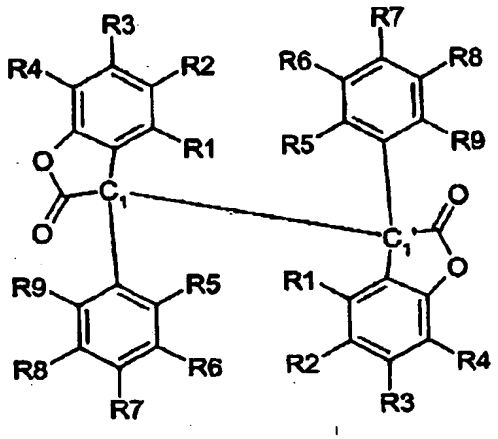
25. A periodically thermally cycling system, including a composition that is subject to substantially more oxidative degradation during a high temperature portion of the thermal cycle than during a low temperature portion of the thermal cycle, the system comprising:

a compound, capable of reversible dissociation in response to temperature changes of the composition upon repeated thermal cycling between the low temperature portion of the thermal cycle and the high temperature portion of the thermal cycle, so as to provide an amount of an active antioxidant species during the high temperature portion of the thermal cycle that is substantially larger than an amount of the active antioxidant species provided during the low temperature portion of the thermal cycle.

26. The system according to claim 25, wherein the compound is a thermally activatable dormant antioxidant species.

27. The system according to claim 25, wherein the compound is a dimeric compound that reversibly dissociates to form two carbon-centered radicals, each of the two carbon-centered radicals being active antioxidant species.

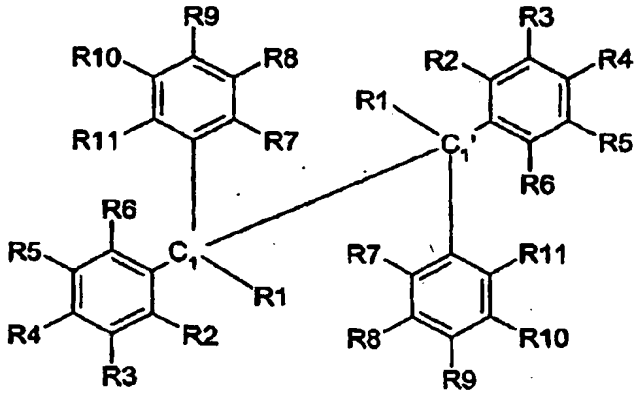
28. The system according to claim 25, wherein the compound is selected from those of formula I:



I

wherein R1 to R9 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl.

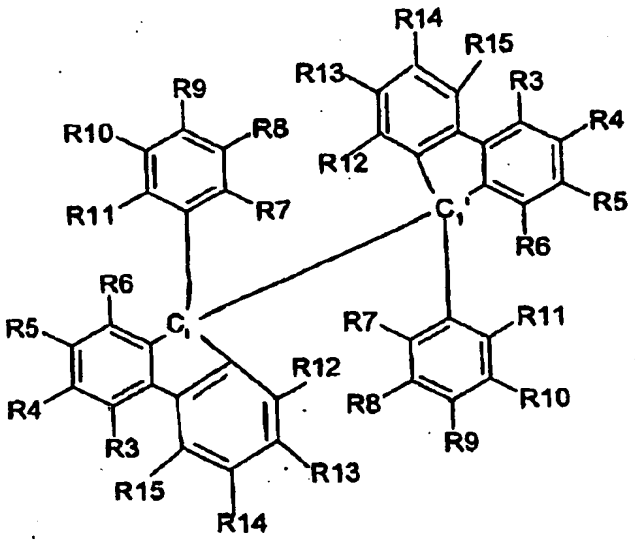
29. The system according to claim 25, wherein the compound is selected from those of formula II:



II

wherein R1 represents an electron withdrawing group, most preferably nitrile, and R2 to R11 are the same or different, each representing a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl.

30. The system according to claim 25, wherein the compound is selected from those of formula III:

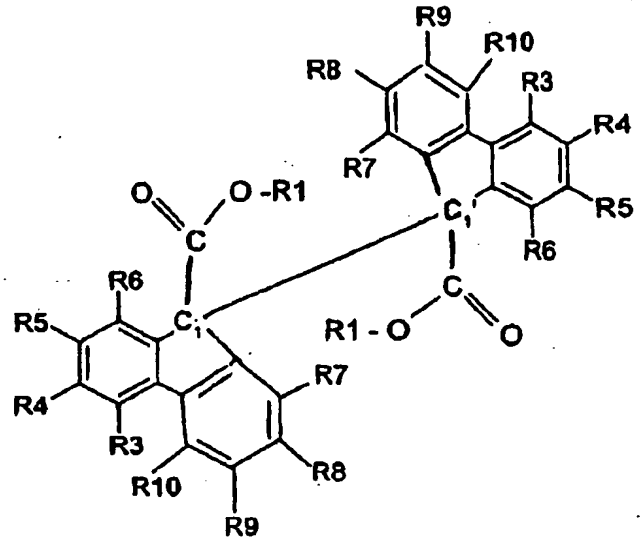


III

wherein R3 to R15 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl.

31. The system according to claim 25, wherein the compound is selected from those of formula IV as described herein, wherein R1 and R3 to R10 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl.

32. The method according to claim 1 or claim 10, utilizing a compound selected from those of formula IV.



IV

wherein R1 and R3 to R10 are the same or different, each representing hydrogen or a substituent selected from the following non-limiting group: linear C_1 -C_{18} alkyl, branched C_1 -C_{18} alkyl, linear C_2-C_{18} alkenyl, branched C_2-C_{18} alkenyl, linear C_2-C_{18} alkynyl, branched C_2-C_{18} alkynyl, C_5 -C_8 cycloalkyl optionally substituted with one or more C_1-C_{18} alkyl, and C_6 -C_{20} aryl optionally substituted with one or more C_1-C_{18} alkyl.

33. An antioxidant precursor compound of the formula:

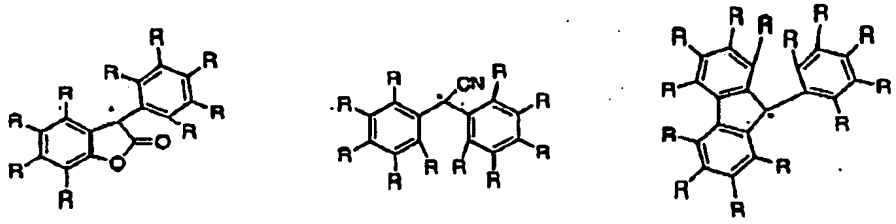
A - B

wherein A and B are the same or different, each of A and B comprise a monocyclic or multicyclic aromatic and / or heterocyclic ring system, optionally substituted at one or more positions;

and wherein A and B are connected via a labile bond, and are susceptible to disassociation through breakage of the labile bond upon exposure of said compound to a predetermined temperature shift from a lower temperature to a higher temperature, thereby to generate corresponding free radicals A and B suitable for use as antioxidants.

34. The compound according to claim 33, wherein A and B are identical.

35. The compound according to claim 33 or claim 34, wherein each of A and B are selected from the group consisting of:



wherein each aromatic or heterocyclic ring may be unsubstituted or substituted with one or more substituents.

36. The antioxidant precursor compound according to claim 33, wherein the compound has a formula selected from a compound of formula I, II, III, and IV as described herein.

37. The antioxidant precursor compound according to claim 33, with the proviso that the compound is not the compound of formula (11) disclosed in United States Patent 5,367,008 or the compound of formula (10) disclosed in United States Patent 5,428,177 or the dimeric form of Irganox HP-136 (Ciba Speciality Products) or related dimeric products.

38. Use of a compound according to claim 33 as a selectively activatable antioxidant.

39. An antioxidant composition selectively transferable between:

(a) a low temperature non-active state wherein the composition comprises a dimeric compound A-B substantially devoid of antioxidant properties; and

(b) a high temperature active state wherein the composition comprises monomeric free radicals A and B, at least one of which exhibits antioxidant properties.

40. The antioxidant composition according to claim 39, wherein the compound A-B is the compound of Formula I, II, III, IV, IA, IB, IIA, or IIIA, as described herein.

41. A method for selectively modulating a concentration of antioxidant molecules in a reaction mixture or target environment, the method comprising the steps of:

(a) providing a composition according to claim 39 or claim 40;

(b) adding the composition to the reaction mixture or target environment;

(c) adjusting the temperature of the reaction mixture or target environment so as to modulate the concentration of antioxidant molecules in accordance with the degree of association or disassociation of A and B.

42. A compound of formula IA, IB, IIA or IIIA as described herein.

ABSTRACT

Selected processes and systems require careful modulation of antioxidant concentrations. The present invention provides dimeric compounds that are capable of reversible dissociation into corresponding monomer radicals, with antioxidant properties, upon exposure to a predetermined temperature shift. Furthermore, the invention pertains to uses of these compounds, corresponding compositions comprising the compounds, and corresponding methods of modulating antioxidant activity in a defined reaction mixture or system. The compounds, compositions and methods of the present invention can be applied to a wide range of systems that require careful modulation of antioxidant concentrations. The capacity of the compounds of the present invention to switch reversibly between non-active (dimeric) and active antioxidant (monomeric) states provides significant advantages over the systems of the prior art.

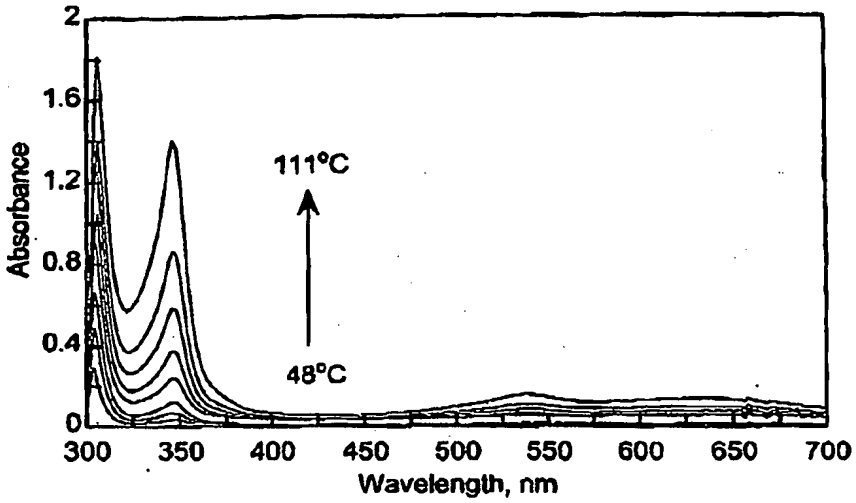


Figure 1

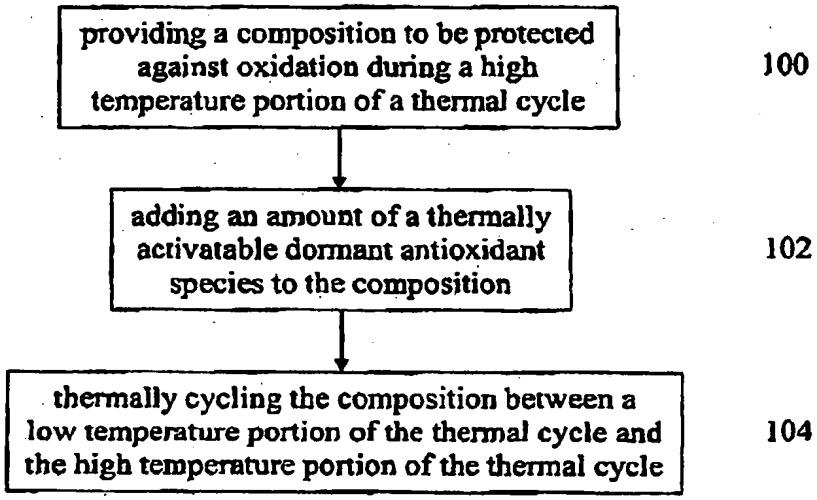


Figure 2

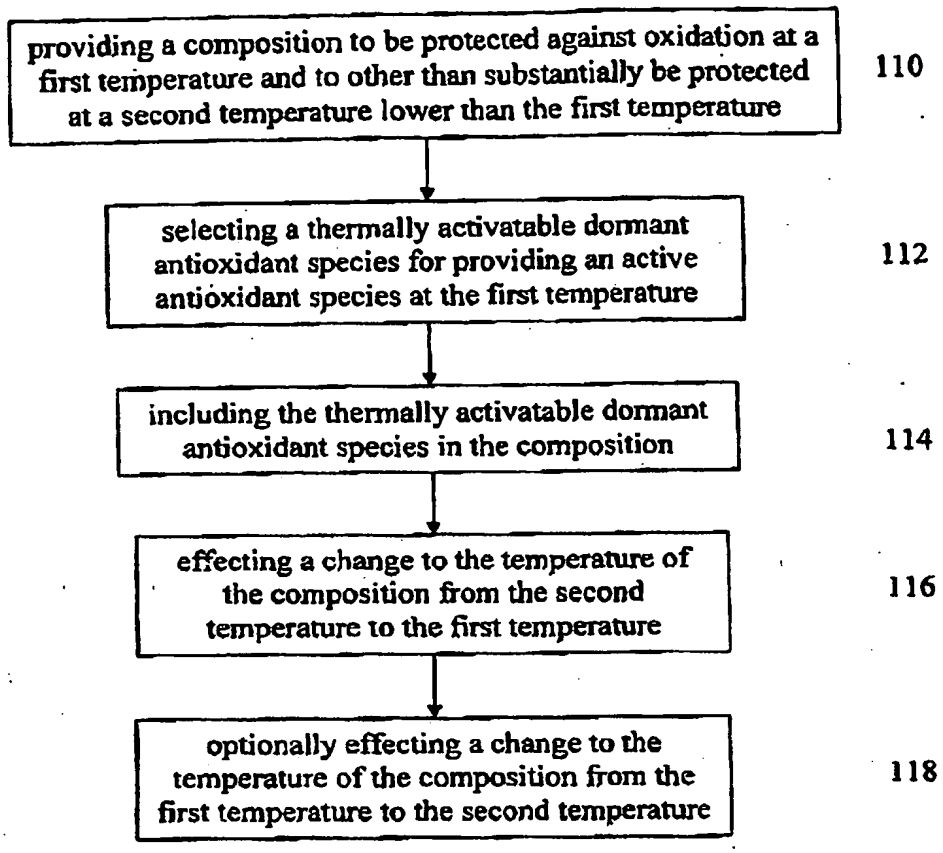


Figure 3

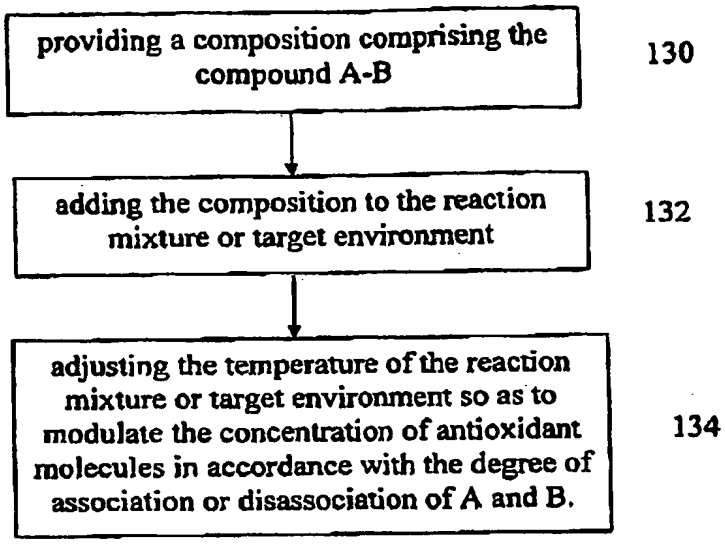


Figure 4

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION CONCERNING
SUBMISSION OR TRANSMITTAL
OF PRIORITY DOCUMENT

(PCT Administrative Instructions, Section 411)

To:

MEE, Trevor R.
Kirby Eades Gale Baker
Box 3432, Station D
Ottawa, Ontario K1P 6N9
CANADA

Date of mailing *(day/month/year)* 06 April 2005 (06.04.2005)	
Applicant's or agent's file reference 57128-PT	**IMPORTANT NOTIFICATION**
International application No. PCT/CA05/000068	International filing date *(day/month/year)* 21 January 2005 (21.01.2005)
International publication date *(day/month/year)*	Priority date *(day/month/year)* 22 January 2004 (22.01.2004)
Applicant UNIVERSITY OF OTTAWA et al	

1. By means of this Form, which replaces any previously issued notification concerning submission or transmittal of priority documents, the applicant is hereby notified of the date of receipt by the International Bureau of the priority document(s) relating to all earlier application(s) whose priority is claimed. Unless otherwise indicated by the letters "NR", in the right-hand column or by an asterisk appearing next to a date of receipt, the priority document concerned was submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b).

2. *(If applicable)* The **letters "NR"** appearing in the right-hand column denote **a priority document which, on the date of mailing of this Form, had not yet been received by the International Bureau** under Rule 17.1(a) or (b). Where, under Rule 17.1(a), the priority document must be submitted by the applicant to the receiving Office or the International Bureau, but the applicant fails to submit the priority document within the applicable time limit under that Rule, **the attention of the applicant is directed** to Rule 17.1(c) which provides that no designated Office may disregard the priority claim concerned before giving the applicant an opportunity, upon entry into the national phase, to furnish the priority document within a time limit which is reasonable under the circumstances.

3. *(If applicable)* **An asterisk (*)** appearing next to a date of receipt, in the right-hand column, denotes **a priority document submitted or transmitted to the International Bureau but not in compliance with Rule 17.1(a) or (b)** (the priority document was received after the time limit prescribed in Rule 17.1(a) or the request to prepare and transmit the priority document was submitted to the receiving Office after the applicable time limit under Rule 17.1(b)). Even though the priority document was not furnished in compliance with Rule 17.1(a) or (b), the International Bureau will nevertheless transmit a copy of the document to the designated Offices, for their consideration. In case such a copy is not accepted by the designated Office as the priority document, Rule 17.1(c) provides that no designated Office may disregard the priority claim concerned before giving the applicant an opportunity, upon entry into the national phase, to furnish the priority document within a time limit which is reasonable under the circumstances.

Priority date	Priority application No.	Country or regional Office or PCT receiving Office	Date of receipt of priority document
22 January 2004 (22.01.2004)	60/537,882	US	30 March 2005 (30.03.2005)

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